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GENERAL SURFACE GEOPHYSICS

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Contents

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1.0 PURPOSE

This set of related procedures describes the general technologies available to meet project data collection objectives by using non-intrusive surface geophysical methods. The surface geophysical methods described herein may be useful in attaining the following data collection objectives: waste characterization (physical limits in two or more dimensions), waste consistency, buried objects, likely water levels, possible shallow plume distribution, local hydrogeologic conditions, and geologic structural conditions. The seven technologies included are electromagnetic conductivity, electrical resistivity, seismic reflection and refraction, magnetometry, gravity, ground penetrating radar, and self-potential. These technologies all measure bulk earth properties through indirect means. Such technologies are not considered to be "stand alone," but are intended to be utilized in conjunction with direct sampling methods such as test pits, soil test boring, and rock coring. Typically, geophysical techniques are referred to as "surveys" due to the inferred nature of the data obtained.

2.0 SCOPE

2.1 Applicability

These procedures provide instruction for the general planning, selection, and implementation of geophysical surveys that may be considered during investigations of hazardous waste sites. These procedures are applicable to all personnel using geophysical field methods supporting the Environmental Restoration program. Seven methods are discussed from the standpoint of applicability to site investigation.

2.2 Training

The seven methods listed in section 1 require college level instruction in geology and geophysical methods. At least one field team member must be college-trained and have experience in the data collection objectives of surface geophysical methods. One field team member must be well versed in the use, maintenance, and calibration of the equipment to be used. The field team leader is responsible for monitoring the proper implementation of these procedures. All field personnel should document that they have read and do understand these procedures and the procedures in SOP Section 1.0, General Instructions.

Interpretation of the geophysical data acquired requires a significantly higher level of training than that required to implement the survey or to process the geophysical data. The person responsible for interpreting the geophysical data is required to have an M.S. or equivalent in geology, geophysics, geological engineering, or geological sciences.

3.0 DEFINITIONS AND ABBREVIATIONS

3.1 Definitions

A. Electromagnetic conductivity: The ability of a material to conduct electrical time-varying current. In isotropic material, the reciprocal of resistivity.

B. Electrode: A piece of metallic material that is used as an electrical contact with a nonmetal.

C. Electrical Resistivity: Observation of electric fields caused by current introduced into the ground as a means for studying earth resistivity.

D. Ground Penetrating Radar: A system in which short wavelength electromagnetic waves are transmitted, and the back scattered electromagnetic energy from reflecting objects is detected.

E. Magnetometry: The measurement of a component or element of the geomagnetic field at different locations. Such measurements are usually made either to map the broad patterns of the Earth's main field or local anomalies that exist due to variations in magnetization (either natural or man-made).

F. Magnetometer: An instrument for measuring magnetic-field strength. Such instruments typically measure either the vertical component of the field or the amplitude of the magnetic field (often termed the total intensity).

G. Seismic Refraction: The change in direction of a seismic ray upon passing into a medium with a different velocity. Also, a method of mapping geologic structure by using head waves involving energy that enters a high-velocity medium (refractor) near the critical angle and travels in the high-velocity medium nearly parallel to the refractor surface.

H. Seismic Reflection: The energy or wave from a seismic source that has been reflected (returned) from an acoustic contrast (reflector) or series of contrasts within the earth. Also, a method of imaging the subsurface by recording, usually with a multichannel recorder, reflected seismic energy generated by a surface or near-surface seismic energy source.

I. Contractor-Specific Geophysical Procedure: A contractor-supplied, specific procedure or set of procedures for making and interpreting measurements of physical properties of the earth to determine subsurface conditions, usually with an economic or geotechnical objective.

J. Instrumental Drift: A systematic change in the output of a given surface geophysical system due to causes inherent in the system, such as changing equipment temperature or deterioration of an electronic component.

K. Calibration: A test or tests performed against known standards with a given surface geophysical system to verify that the system is functioning properly and to provide calibration values which allow the data from the system to be used quantitatively.

L. Survey Notes or Data: Information obtained during a surface geophysical survey that is written in a field book or recorded by an electronic or optical recorder.

M. Surface Geophysical Technical Specifications: A set of technical specifications prepared by the Operable Unit Project Leader for a particular type of geophysical survey. Such specifications define the type of geophysical survey to be employed, the precision required of the survey, the data accuracy and repeatability, the data recording format and medium, and so forth.

N. Self-potential or spontaneous potential: The measurement of naturally-occurring, potential differences between points on the earth's surface. Such differences typically arise from either conductivity variations in the earth or fluid flow within the earth.

3.2 Abbreviations

CSGP - Contractor-specific geophysical procedures
EM - Electromagnetic conductivity
ER - Electrical resistivity
GPR - Ground penetrating radar
OUPL - Operable unit project leader
PDCO - Project data collection objectives
QA/QC - Quality assurance/quality control
SGTS - Surface geophysical technical specifications
SP - Self-potential (sometimes called spontaneous potential)
SR - Seismic reflection/refraction
FTL - Field Team Leader

4.0 BACKGROUND AND/OR CAUTIONS

4.1 Health and Safety Concerns

Potential hazards during a surface geophysical operation are associated with machinery, electrical devices, weather, possible contact with contaminants, and other hazards. Some of these hazards are listed below; this list is not intended to be comprehensive. A Laboratory Standard Operating Procedure (SOP) or Special Work Permit (SWP) may be required when certain instrumentation is used. Refer to the Laboratory's Environmental, Safety, and Health manual for specific requirements relevant to SOPs and SWPs.

4.1.1 Machinery

Ground penetrating radar (GPR), electromagnetic conductivity (EM), and electrical resistivity (ER) sources are somewhat mechanical; and hazards such as tipping, rotating, or moving machinery are present.

Seismic reflection/refraction (SR) sources are mechanical and have hazards such as tipping, high pressures, pulleys, etc. Occasionally, explosive sources are tried; use of such sources must adhere to an approved Laboratory Standard Operating Procedure.

4.1.2 Electrical Devices

Direct electrical hazards - such as electrical shock and burns or electrical fires from sources, electrodes, long wires - are possible, especially using ER.

Indirect hazards-such as failure of portable generators, batteries, high pressure hoses, etc. - are possible using several of the methods discussed herein.

4.1.3 Weather

High winds increase machinery and electrical hazards.

Rain increases electrical shock hazard, especially in ER.

Lightning is a potential hazard, especially where long wires are used along the ground.

Exposure (e.g., heat exhaustion or hypothermia) is a hazard in adverse weather or if work continues beyond normal working hours.

4.1.4 Contamination

All equipment used at a site known or suspected to be contaminated must be monitored for contamination. Site workers should be aware of surface geophysical operations at all times and read and understand the SOPs related to Health and Safety in the Field.

4.1.5 Other Hazards

Fuel fires

Carbon monoxide fumes

Personnel problems such as inadequate training, carelessness or inattention, and impairment from medication, drugs, ailments, etc.

4.2 Overview of Surface Geophysical Techniques

4.2.1 Introduction

In environmental restoration applications, surface geophysical techniques are used for the in-situ determination of physical, chemical, geological, and hydrological parameters in site characterization and waste sites. Surface geophysical measurements can be used to help solve waste cleanup problems as part of initial site characterization, during remediation, and for post-remediation monitoring.

For accurate results to be achieved with a given surface geophysical system, it is essential that the system be calibrated against accepted standards and monitored for any malfunction or significant drift of the system calibration. In addition, the data must be corrected for non-standard conditions (conditions other than those encountered in the calibration).

4.2.2 Types of Surface Geophysical Methods

4.2.2.1 Electromagnetic Conductivity

The EM method provides an indirect means of measuring the electrical conductivity or resistivity of subsurface soil, rock, and groundwater. Electrical conductivity is a function of the type of soil and rock, its porosity, and the fluid composition and saturation. In most cases the conductivity of the pore fluids will be responsible for most of the measurement. Accordingly, the EM method applies both to assessment of natural geohydrologic conditions and to mapping of many types of contaminant plumes. In addition, trench boundaries, buried wastes, drums, and utility lines can be located with EM techniques. The EM technology is versatile; data may be collected either continuously or on a station-by-station (grid) basis.

Note that the EM technique measures earth conductivity by inducing eddy currents into the near-surface materials. The inducing electromagnetic field usually has a frequency close to 10 kHz; commercially available instruments have depth penetrations of roughly 5 meters (the actual depth of penetration depends upon the local conductivity structure).

4.2.2.2 Electrical Resistivity

Electrical resistivity surveys provide information about the subsurface distribution of the ground resistivity. The information can be used to infer groundwater quality and lithologic and geological information. Both horizontal and vertical changes in ground resistivity can be mapped by resistivity surveys. However, in practice, resistivity surveys are mostly used to determine the vertical changes, and lateral resistivity changes are more easily mapped by electromagnetic surveys. Often, electromagnetic and resistivity surveys are used together. ER surveys are normally performed on a station-by-station basis following linear (cross-section) or grid patterns. The ER method applies to assessment of natural geohydrologic conditions and to mapping of contaminant plumes. In some conditions, trench boundaries, buried wastes, and utility lines can be located with ER techniques.

4.2.2.3 Seismic Reflection/Refraction

Seismic techniques have been useful in some instances for assessing subsurface geohydrologic conditions such as depth to bedrock; depth thickness and dip of lithologic units; horizontal and vertical extent of anomalous geologic features (folds, faults, and fractures); the approximate depth to the water table; and, in conjunction with geophysical well log data, the porosity and permeability of lithologic units. Seismic techniques have also been used to delineate the boundaries of subsurface bulk waste trenches and the depth of landfills.

Seismic methods are relatively expensive to use and have poor spatial resolution (rarely < 0.5 meters) when compared to the resolution possible using GPR. However, the useful depth of penetration for seismic methods can be quite large (hundreds of meters), and the method can often provide results when all the other methods discussed herein fail.

4.2.2.3.1 Seismic Reflection

The method of seismic reflection consists of measuring the two-way travel times of compressional waves generated by a surface source and reflected from subsurface interfaces. Depths to each reflecting interface can be inferred from reflection two-way travel times combined with layered velocity information.

Higher subsurface resolution of shallower layers is possible with shallow reflection techniques than with refraction methods (see 4.2.2.3.2). Modern multichannel engineering seismographs have filtering capabilities that allow later arriving wide-angle reflections to be separated from earlier refraction arrivals.

4.2.2.3.2 Seismic Refraction

The method of seismic refraction consists of measuring the travel times of compressional waves that are generated by a surface source, critically refracted from subsurface interfaces, and received by surface receivers. First-arrival travel times of seismic energy plotted against source-to-receiver distance on a time-distance curve are characteristic of the material through which they travel. The number of line segments on the time-distance plot indicates the number of layers. The inverse slope of a line segment indicates the apparent seismic velocity of a layer.

Seismic velocities obtained from a refraction survey over an area do not always agree with those obtained from a reflection survey over the same area. The differences may be because refraction velocities are obtained from rays traveling parallel to the top of a layer, whereas reflection velocities are obtained from waves traveling perpendicular to the strata at the bottom of the layer.

The technique of seismic refraction has been used to a greater extent than seismic reflection in the subsurface characterization of hazardous waste sites.

4.2.2.4 Magnetic Methods

Magnetometer surveys are used to identify areas of anomalous magnetic field strength. Although natural conditions may cause anomalies, shallowly buried ferrous metal objects (for example, steel drums) exhibit strong anomalies that are rarely confused with natural sources. Generally, any strong anomaly must be considered suspicious and therefore should be examined by direct sampling methods. Magnetic studies are performed on a station-by-station (grid) basis. The data are typically presented by contouring, although maps using colors rather than contours may be used, as well.

The magnetic methods described are applicable to locating buried drums and other ferrous metal objects; locating waste pits that contain ferrous metal; locating underground utilities such as pipelines, cables, tanks, and abandoned well casings; clearing drill sites; and identifying geologic features that exhibit sufficient magnetic contrast.

Ferromagnetic metal location and depth of burial can be inferred from the shape and width of the anomaly. The location of metal using magnetometry facilitates excavation without puncturing metal containers. Underground utilities, which are traceable with magnetics, often lie within loosely filled trenches and may provide permeable pathways for groundwater flow. Magnetometry is used in clearing drilling sites to select locations that are free of drums, detectable underground utilities, and other ferrous objects.

Under certain conditions where sufficient contrast in natural magnetization between geologic units exists, magnetic methods may be useful in identifying geologic structures such as folding, faulting, buried drainage channels, bedrock topography, and igneous intrusions. In addition, if sufficient subsurface contrast exists, it may even be possible to delineate past trench or pit burial sites where nonmetallic materials were disposed.

Interferences from surface metals, fences, powerlines, and other above ground sources - which generally lie closer to the magnetometer sensor than buried targets - may mask the targets. Corrections for these interferences cannot always be done, in which cases data obtained near such interferences must be excluded. Corrections for interferences from geologic conditions and surface objects that have small magnetic moments in comparison to the target may be possible, although such corrections are rarely used.

4.2.2.5 Gravity Methods

Surface gravity measurements are occasionally useful for quantifying the volume of mass deficit or excess. The method is affected by mass density variations and thus can be useful for estimating the volume of a landfill or tank, if the density contrast between the landfill or tank and the surrounding medium is known or can be estimated reliably. The method is not particularly sensitive and typically requires large volumes of material to be missing (or in excess) to be useful.

To be useful for environmental applications, gravity methods require that each gravity measurement location be known precisely, especially its elevation, and that modern, highly precise instrumentation be used. Modern instrumentation is capable of reliably measuring gravity differences as small as 3 microGals; instrumentation that is incapable of such precision is usually not useful for environmental applications.

4.2.2.6 Ground Penetrating Radar

Ground penetrating radar has been demonstrated to be useful in defining landfill cover thickness and the presence of shallow (less than 3 m) burial sites. The method may be utilized on a station-by-station or continuous recording basis, but is more often used in the continuous mode.

GPR data are often used to produce a continuous subsurface profile through the use of a linear strip chart recorder, although digital recording and subsequent processing will probably supplant the older analog methods in the near future. The following is a partial list of major GPR uses related to hazardous waste site investigations.

- Delineate the locations of buried drums, tanks, cables, and pipelines.
- Define the boundary of disturbed versus original ground, such as a landfill or a trench.
- Map water tables.
- Delineate stratigraphic layers such as clay, till, or sand.
- Define natural subsurface features, such as buried stream channels, lenses, and voids (caves).

Although GPR cannot provide definitive information on subsurface conditions, the data are desirable largely because of the very high spatial resolution that is attainable.

GPR instruments are limited with regard to sensitivity, resolution, and penetration. Field experience, published references, and operators' manuals should be used when an evaluation of instrumentation versus capability is desired.

Interpretation of radar data generally becomes more complex as the contrast in electrical properties between background and target areas becomes less. Several small, closely-spaced targets may not be sensed as multiple anomalies, but as one large anomaly.

4.2.2.7 Self-Potential Methods

Self-potential methods utilize naturally-occurring differences in electrical potential between locations on the surface. Historically, such measurements have been used to prospect for metallic ore bodies, for the electrical conductivity of such bodies is typically much higher than their host rocks; such conductivity variations can give rise to measurable potential differences, which are what the SP method is based upon. In most applications relevant to environmental restoration, however, the SP method is used to measure potential differences resulting from fluid flow in porous materials. Sometimes such potentials are termed *streaming potentials*. In such cases, measurements are usually made over time, rather than as a function of spatial position. As fluids pass through porous media, electrodes (typically porous pots) on the surface are used to measure the time changes in potential differences. Such measurements are then used to infer the rate and geometry of the fluid moving in the porous medium below.

Because the potential differences usually encountered in SP surveys are quite small (often less than 50 milliVolts), voltmeters or other recording devices should be designed to measure very small voltages. Additionally, accurate calibration of such equipment is essential.

4.2.3 Calibration

Accurate calibrations are necessary for the data to be used quantitatively; calibrations also play an important role in monitoring surface geophysical techniques over time. The contractor of the surface geophysical technique must include a set of written calibration procedures for all geophysical equipment involved in quantitative measurements. The surface geophysical contractor is responsible for maintaining full and complete documentation for all calibrations for all equipment and shall provide copies of such records as required by the field team leader (FTL).

Regular calibrations traceable to accepted standards are performed at specified time intervals as well as every time a surface geophysical instrument is modified or repaired. Some instrumentation requires field or job-site calibrations to be performed immediately before and after a geophysical survey.

5.0 EQUIPMENT

The list of equipment required for surface geophysical surveys varies with the contractor and the specific technique(s) being used. Refer to the surface geophysical technical specifications (SGTS) and the contractor-specific geophysical procedures (CSGP) for the required lists.

6.0 PROCEDURES

Operation of the surface geophysical equipment will be in accordance with applicable industry standards and regulatory requirements.

6.1 Surface Geophysical Technical Specifications

Before soliciting bids on any surface geophysical contract for an operable unit, detailed surface geophysical technical specifications must be prepared as part of the project data collection objectives (PDCO). The success of the surface geophysical technique depends to a large degree on these specifications. The SGTS must define the type of surface geophysical system; the techniques to be used; the parameters required; the data precision, accuracy, and repeatability; the sample interval, calibration schedules and requirements; data formats and media; and so forth. The SGTS will be prepared by the operable unit project leader (OUPL) and the FTL responsible for data collection objectives. The Environmental Restoration (ER) Program's principal investigator for surface geophysics should be consulted for assistance in the preparation of the SGTS.

6.2 Before Letting the Surface Geophysical Contract

Specific, detailed procedures depend on the type of surface geophysical system and the geophysical contractor being used. These contractor-specific geophysical procedures must be prepared and submitted by the prospective geophysical contractor for approval by the FTL for the PDCO before the contract is finalized. The CSGP should conform to the general procedures given in this General Surface Geophysics SOP.

6.3 Preparing for the Surface Geophysical Survey

It is the FTL's responsibility to

- ensure that approval for property access has been obtained.
- review the site project data collection objectives and health and safety plan for specific information on field activities. Verify that the surface geophysical equipment meets specifications outlined in the SGTS. Verify that the CSGPs meet the specifications outlined in the SGTS for each surface geophysical method to be applied.
- have the work site cleared of all brush and minor obstructions and have the location of utilities properly staked and identified.
- ensure that the specific surface geophysical equipment to be used has completed a regular calibration within the required time period prior to the surface geophysical operation as specified in the SGTS. Ensure that the calibration(s) met the accuracy requirements given in the SGTS. Ensure that the surface geophysical equipment has completed a regular calibration

subsequent to any repair or modification even if the equipment is not yet due for a routine regular calibration; ensure that the calibration was within acceptable accuracy tolerances as defined in the SGTS.

- ensure that all surface geophysical equipment has been decontaminated prior to use.

- prepare to monitor all surface geophysical equipment used on the site for contamination (Refer to the SOPs in Section 7.0 of this SOP, References, for guidance).

6.4 The Surface Geophysical Survey Operation

It is the FTL's responsibility to

- ensure that surface geophysical survey operations are carried out as specified in the CSGP.

- ensure that all surface geophysical equipment is decontaminated between survey runs.

Because each surface geophysical technique that is to be run must be field-calibrated as required in the SGTS, a field calibration is generally required both immediately before and after a surface geophysical survey is run. The FTL ensures that this process is properly carried out according to the procedures given in the CSGP and that the readings are within acceptable limits as defined in the SGTS.

6.5 After the Surface Geophysical Survey

It is the FTL's responsponsibility to

- ensure that the survey equipment documentation sheets are correct and complete and meet the specifications given in the SGTS. He must sign and date as witness.

- obtain copies of field data in hard copy form (field notes or report) and digital form (for example, magnetic tapes or diskettes), as specified in the SGTS. These field copies are an important part of the data quality record, even though reprocessed data may be submitted by the geophysical contractor at a later time or date.

- ensure that all surface geophysical equipment is accounted for, decontaminated, and ready for transport.

- ensure that the site is restored to pre-survey conditions or as otherwise specified.

7.0 REFERENCES

Contractor-specific surface geophysical survey procedures

LANL-ER-SOPs in Section 1.0, General Instructions

LANL-ER-SOPs in Section 2.0, Health and Safety in the Field

LANL-ER-SOPs in Section 12.0, Curatorial Management Activities

LANL-ER-AP-02.1, LANL ER Records Management Procedure

Surface Geophysical Technical Specifications

Useful reference books include the following.

Bates, R. L., and J. A. Jackson, 1980, *Glossary of Geology*, American Geological Institute, Falls Church, Virginia.

Benson, R. C., R. A. Glaccum, and M. R. Noel, 1983, *Geophysical Techniques and Sensing Buried Wastes and Waste Migration*, U. S. Environmental Protection Agency, Las Vegas, NV.

Sheriff, R. E., 1991, *Encyclopedic Dictionary of Exploration Geophysics*, Society of Exploration Geophysicists, P. O. Box 702740, Tulsa, OK 74170-2740.

U. S. Environmental Protection Agency, 1987, *Compendium of Superfund Field Operations Methods,* EPA/540/P-87/001, Washington, DC.

U. S. Environmental Protection Agency, Region IV, 1991, *Environmental Compliance Branch Standard Operating Procedures and Quality Assurance Manual,* Environmental Services Division, Athens, GA.

8.0 RECORDS

Field reports and copies of field data, signed by the surface geophysical contractor representative and the field team leader or other approved witness as specified in the SGTS.

Digital data on magnetic tape or as otherwise specified in the SGTS.

Completed surface geophysical quality report for each geophysical survey run, as specified in the SGTS. Completing this quality report is the responsibility of the field team leader.

Calibration records as specified in the SGTS.

The OUPL is responsible for transfer of these records to the ER Records Processing Facility in accordance with the Procedure for LANL ER Records Management (LANL-ER-AP-02.1).

9.0 ATTACHMENTS

None